

## OPTICAL SYSTEMS WITH MULTI-LAYER HOLOGRAPHIC COMBINERS

[0001] This application claims the benefit of provisional patent application No. 62/772,985, filed Nov. 29, 2018, which is hereby incorporated by reference herein in its entirety.

### BACKGROUND

[0002] This relates generally to optical systems and, more particularly, to optical systems for displays.

[0003] Electronic devices may include displays that present images close to a user's eyes. For example, devices such as virtual reality and augmented reality headsets may include displays with optical elements that allow users to view the displays.

[0004] It can be challenging to design devices such as these. If care is not taken, the components used in displaying content may be unsightly and bulky and may not exhibit desired levels of optical performance.

### SUMMARY

[0005] An electronic device such as a head-mounted device may have one or more near-eye displays that produce images for a user. The head-mounted device may be a pair of virtual reality glasses or may be an augmented reality headset that allows a viewer to view both computer-generated images and real-world objects in the viewer's surrounding environment.

[0006] The near-eye display may include a display module that generates image light and an optical system that redirects the image light from the display unit towards an eye box. The optical system may be, for example, a multi-layer holographic combiner. The optical system may have first hologram structures and second hologram structures overlapping the first hologram structures. The first hologram structures may receive the image light at angles external to a volume between the first and second hologram structures. The first hologram structures may be configured to replicate the image light from multiple incident angles over multiple output angles onto the second hologram structures. The second hologram structures may focus the replicated image light onto the eye box.

[0007] In one suitable arrangement, the first hologram structures include transmission holograms and the second hologram structures include reflection holograms. In another suitable arrangement, the first hologram structures include reflection holograms and the second hologram structures include transmission holograms. In yet another suitable arrangement, both the first and second hologram structures include reflection holograms. The optical system may occupy relatively little space within the device, may exhibit a relatively large field of view, may have non-planar shapes, may replicate an image across the eye box such that no perspective change is observed by a user as their eye transitions through the eye box (e.g., for a wide range of user physiologies), and may allow rendering of virtual objects at any depth from the user, as examples.

[0008] If desired, the device may include an image sensor. The optical system may redirect a first portion of the image light to the eye box and a second portion of the image light to the image sensor. The image sensor may generate image data based on the second portion of the image light. Control circuitry may identify distortions in the image data indica-

tive of a change in position of the optical system relative to the display module. The distortions may be, for example, distortions that are present from the user's perspective at the eye box. The control circuitry may compensate for these distortions by performing feedback adjustments to the image light projected by the display module based on the identified change in position.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a diagram of an illustrative system having a display in accordance with some embodiments.

[0010] FIG. 2 is a diagram of an illustrative display system having a multi-layer holographic combiner with transmission hologram structures for replicating an external image and reflection hologram structures for focusing each replicated image onto an eye box in accordance with some embodiments.

[0011] FIG. 3 is a diagram showing the operation of illustrative transmission hologram structures in a multi-layer holographic combiner in accordance with some embodiments.

[0012] FIG. 4 is a diagram showing the operation of illustrative reflection hologram structures in a multi-layer holographic combiner in accordance with some embodiments.

[0013] FIG. 5 is a diagram showing the operation of an illustrative point-to-plane-wave hologram that may be used in transmission hologram structures and/or reflection hologram structures in accordance with some embodiments.

[0014] FIG. 6 is a diagram showing the operation of an illustrative point-to-nearly-plane-wave hologram that may be used in transmission hologram structures and/or reflection hologram structures in accordance with some embodiments.

[0015] FIG. 7 is a diagram of an illustrative multi-layer holographic combiner having one or more substrates in accordance with some embodiments.

[0016] FIG. 8 is a diagram of an illustrative multi-layer holographic combiner with reflection hologram structures for replicating an external image and transmission hologram structures for focusing each replicated image onto an eye box in accordance with some embodiments.

[0017] FIG. 9 is a diagram showing how separate layers of holographic films may be used for diffracting light of different wavelengths in accordance with some embodiments.

[0018] FIG. 10 is a diagram showing how holograms for diffracting light of different wavelengths may be multiplexed on the same volume of grating medium in accordance with some embodiments.

[0019] FIG. 11 is a diagram of an illustrative multi-layer holographic combiner provided with a curved shape in accordance with some embodiments.

[0020] FIG. 12 is a diagram of an illustrative multi-layer holographic combiner having an optical diffuser and reflection hologram structures in accordance with some embodiments.

[0021] FIG. 13 is a flow chart of illustrative operations involved in recording holograms in accordance with some embodiments.

[0022] FIG. 14 is a diagram of an illustrative hologram recording system for recording transmission hologram structures in accordance with some embodiments.